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(54) Title of the invention: Catadioptric optical system

(57) Abstract

Purpose: To provide a catadioptric optical system which has an optical system in a practically compact size, is capable of providing a large numerical aperture in the ultraviolet band region, has resolution of quarter micron levels, and has each constituent element in compact size in the optical system.

Configuration: A catadioptric optical system is provided which includes a first imaging optical system S1 constructed with refractive members, a concave mirror M1, and a second imaging optical system S2 constructed with refractive members in the order of the advance of a light beam, to project a semiconductor device pattern onto a substrate, and in which at least one refractive member out of the refractive members constituting the first imaging optical system and the refractive members constituting the second imaging optical system has an aspherical surface.

Scope of Patent Claims

Claim 1

A catadioptric optical system which projects a semiconductor device pattern onto a substrate; characterized in that it comprises

a first imaging optical system constructed with refractive members,

a concave mirror, and

a second imaging optical system constructed with refractive members in the order of the advance of a light beam, and

at least one refractive member out of the refractive members constituting the first imaging optical system and the refractive members constituting the second imaging optical system has an aspherical surface.

Claim 2

A catadioptric optical system described in Claim 1; characterized in that

the first imaging optical system includes a first lens group through which light enters only once and a second lens group through which light reciprocates,

a lens in the second lens group closest to the concave mirror is a negative lens, and

light coming through the second lens group images the semiconductor device pattern once before entering the second imaging optical system.

Claim 3

A catadioptric optical system described in Claim 1 or Claim 2; characterized in that an optical path•deflection member is arranged between the first imaging optical system and the second imaging optical system.

Claim 4

A catadioptric optical system described in Claim 1 to Claim 3; characterized in that the refractive members in the first imaging optical system and the refractive members in the second imaging optical system are formed of quartz and fluorite, or any one of the glassy materials.

Claim 5

A catadioptric optical system described in Claim 1 to Claim 4; characterized in that the concave mirror is aspherically shaped.

Detailed Description of the Invention

[0001]

Technical Field of Utilization

The present invention relates to an optical system in a projection exposure apparatus used for manufacturing semiconductor devices or liquid crystal display devices and the like with a photolithographic processing. The invention specifically

relates to a catadioptric optical system which has resolution of quarter micron levels in the ultraviolet wavelength region by using a reflective mirror as an element of the optical system.

[0002]

Prior Art

In photolithographic processing for manufacturing semiconductor devices and the like, a projection exposure apparatus is used in which a semiconductor device pattern printed onto a photomask or reticle (hereafter both are referred to as reticle) is exposed via a projection optical system onto a substrate such as a wafer or glass plate (hereafter both are referred to as a wafer) coated with photoresist and the like. As integration of semiconductor devices and the like advances, demand for a projection optical system used in projection exposure apparatus requiring more stringent resolution increases. In order to fulfill this need, using a shorter band illumination light and a larger numerical aperture (NA) for a projection optical system has become essential. Various technologies have been proposed in order to meet the requirement in which a projection optical system is constructed with a so called "catadioptric optical system" which is a combination of a reflective system and a refractive system.

[0003]

For example, Japanese Patent Application Publication No. S63-163319 and Japanese Patent Application Publication No. H5-25170 disclose a catadioptric optical system which uses an exposure region including light on an optical axis. In addition, Japanese Patent Application Publication No. H7-111512 and US Patent No. 4,779,966 disclose an optical system which uses a ring-shaped exposure region, rather than the optical axis.

[0004]

Problems to Be Solved by the Invention

In the catadioptric optical system using an exposure region which includes light on the optical axis, a beam splitter having a transmittive reflective surface is required for splitting the optical path. This optical system may easily generate stray light, causing flares or uneven illumination in internal reflections by reflective light from the wafer surface, internal reflections on a refractive surface of the optical systems arranged behind the beam splitter, or on the transmittive reflective surface of a beam splitter and the like. An optical system with a larger numerical aperture requires a larger beam splitter and a longer exposure time due to the loss in light intensity. This in turn, causes a decrease in throughput of the semiconductor manufacturing process. Also, as disclosed in Japanese Patent Application Publication No. H6-300973, a polarizing beam splitter is required to prevent loss of light intensity, however, it is very difficult to manufacture a large polarizing beam splitter and its use gives unfavorable imaging performance due to the uneven film thickness

of the transmittive reflective layer, angle characteristics, absorption, and phase change of the light, etc.

[0005]

On the other hand, in the catadioptric optical system disclosed in US Patent No. 4,779,966 using a ring-shaped exposure region, a reflective optical system is employed on the reduced side toward a wafer surface rather than at an interim image. However, since the NA is larger on the reduced side than on the reticle surface side, it is difficult to split the optical path, making it impossible to increase the NA of the optical system. This does not provide excellent resolution. Increase in the size of the concave mirror is also unavoidable.

[0006]

In the catadioptric optical system disclosed in Japanese Patent Application Publication No. H7-111512 a ring-shaped exposure region in the same manner, the first imaging optical system including a concave mirror for forming an interim image is constructed with an optical system in perfect symmetry, and the size of the interim image remains the same as the real size of the reticle surface. In this way, the possibility of generating aberrations in the first imaging lens is reduced, however, the second imaging optical system solely takes magnification of the whole system, which gives a heavier load onto the second imaging optical system. Especially, when a large NA is required for the optical system, increase in the size and complexity of the second imaging optical system are also unavoidable.

[0007]

In consideration of the above problems, the present invention intends to provide a catadioptric optical system which attains a large numerical aperture in the ultraviolet band region in the practical size of the entire optical system, obtain the photolithographic resolution of quarter micron levels, and is constructed with components of reduced sizes.

[0008]

Means to Solve Problems

In order to achieve the purpose described above, the present invention provides a catadioptric optical system which projects a semiconductor device pattern onto a substrate and includes a first imaging optical system S1 constructed with refractive members, a concave mirror M1, and a second imaging optical system S2 constructed with refractive members in the order of the advance of a light beam, and at least one refractive member out of the refractive members constituting the first imaging optical system and the refractive members constituting the second imaging optical system has an aspherical surface.

[0009]

Embodiments

In the present invention as described, the reduction of generating aberrations of high orders and increase in the NA of the optical system are possible, and increase in the complexity and size of the optical system can be prevented, by employing aspherical shape in the refractive member. Shifting the refractive surface from a spherical surface ideally bends light flux which exists around the lens surface. This makes it possible to correct aberrations of high orders without broadening the entire flux.

[0010]

Particularly, if aspherical refractive surfaces are introduced to the first imaging optical system S1, the size of the first imaging optical system S1 can be prevented from increasing, and if aspherical refractive surfaces are introduced to the second imaging optical system S2, the size of the second imaging optical system S2 can also be prevented from increasing. Also, it is preferable that the first imaging optical system S1 includes a first lens group G1 through which light enters only once and a second lens group G2 through which light makes a round trip, the lens closest to the concave mirror M1 of the second lens group G2 is a negative lens LS, and light coming through the second lens group G2 images a semiconductor device pattern once before entering the second imaging optical system S2. Particularly, this configuration of the optical system allows decrease in the size of each of its component members. In addition, the configuration is very effective in reducing chromatic aberration on the axis in which the negative lens LS which is closest to the concave mirror M1 in the second lens group G2, the concave mirror M1, and the second imaging optical system S2 are arranged in the order of the advance of light and in which the semiconductor device pattern is imaged once before light coming through the second lens group G2 enters the second imaging optical system S2.

[0011]

In the optical system of the aforementioned configuration, it is preferable that the second lens group G2 is constructed with a refractive member having at least two different negative refractive powers and a refractive member having at least two different positive refractive powers. The lens having negative refractive powers is highly effective in correcting coma or spherical aberrations and image curvature and the like. The lens having positive refractive powers is effective for providing in a large NA or exposure region, without increasing the size of the optical system. Moreover, it is desirable that each of the members have at least two lenses in order to compensate for aberrations of the second imaging optical system S2 and to reduce the load for correcting aberrations of the second imaging optical systemS2.

[0012]

Also, it is preferable that the first lens group G1 is constructed with refractive members having at least three different refractive powers. Recently, as the demand

for higher resolution increases, more stringent specifications have been demanded for correcting distortion, image curvature and the like. It is important to adjust these parameters during manufacturing to meet this demand, but the adjustments for a lens positioned in the vicinity of the reticle surface work effectively. However, the second lens group G2 of the present invention is the optical system for both outgoing and incoming light, which is inappropriate for adjustment lenses. For this reason, constructing the first lens group G1 with lenses having at least three different refractive powers makes it possible to adjust distortion or image curvature during manufacturing of optical systems. Also, by utilizing the first lens group G1 in the aforementioned configuration, the working distance in the vicinity of the surface of the reticle R can be increased and a step and scan method of exposure is made possible.

[0013]

The second imaging optical system S2 plays an important role in correcting mainly spherical or coma aberrations to allow the optical system to have a large NA. In the present invention, it is preferable to arrange an optical path deflection member M3 between the first imaging optical system S1 and the second imaging optical system S2. By arranging an optical path deflection member such as a mirror, the entire optical system can be bent, reduction in the entire size of the optical system can be attained.

[0014]

In addition, in the present invention, since short wavelengths in excess of 300nm are used as a light source for exposure, quartz or fluorite is preferably used, which is excellent in light intensity transmitting property, inexpensive, and easy to process. Also in the present invention, the concave mirror M1 can be formed in an aspherical shape. If the concave minor M1 is aspherical, the magnitude of the positive refractive power of the concave mirror M1 can be increased without generating aberrations of high orders, which makes it possible to manufacture compact optical systems having a large NA and also allows correction of chromatic aberration over wideband wavelengths.

[0015]

Furthermore, by forming an aperture stop (variable aperture) in the optical path of the second imaging optical system S2, the coherence factor (σ value) can be adjusted. As a technique to increase focal depth and improve resolution, for example, Japanese Patent Application Publication No. S62-50811 discloses a phase shift technique which is used to shift the phase of a predetermined portion of the reticle pattern from another portion. In the present invention, since the coherence factor (σ value) can be adjusted, there is an advantage of improving the effect of the phase shift technique.

[0016]

Embodiment

Embodiments expressed quantitatively for the catadioptric optical system of the present invention are shown hereinbelow. The catadioptric optical system according to each quantitative embodiment includes, in order from the reticle R side (in the order that light advances), a first imaging optical system S1 constructed with refractive members, a concave mirror M1, and a second imaging optical system S2 constructed with refractive members, the first imaging optical system S1 includes a first lens group G1 through which light enters only once and a second lens group G2 through which light makes a round trip, and a lens closest to the concave mirror M1 in the second lens group G2 is a negative lens LS.

[0017]

In each of the quantitative embodiments, NA=0.6 and aberrations for the image height are corrected within the range of 5 to 18.6. In addition, as an exposure region, the range for the aforementioned image height may be a ring shape or may be a rectangle of 6 × 30 at a distance of 5 from the optical axis. In each table for the first embodiment and the second embodiment, r denotes surface curvature radius and d denotes a distance between surfaces. Glassy materials are denoted as SiO_2 for quartz and CaF_2 for fluorite in each of the tables. A refractive index n for quartz and fluorite at 193.0 nm and a dispersion value 1/ν for those of ± 0.1nm are as follows:

[0018]

	n	1/ν
Synthetic quartz:	1.56019	1780
Fluorite:	1.50138	2550

In addition, in each of the embodiments, an aspherical surface is shown by the following equation, $Z=(Y^2/r)/[1+\mathrm{sqrt}\{1-(1+K)Y^2/r\}]+C_4Y^4+C_6Y^6+C_8Y^8+C_{10}Y^{10}+C_{12}Y^{12}$

where Z: a distance from the top measured in the direction of the optical axis;

Y: a distance from the top measured in the direction perpendicular to the optical axis;

K: a constant of the cone;

r: a curvature radius of the top; and

C_4, C_6, C_8.....: aspherical surface constants for 4-order, 6-order, 8-order.

First Embodiment

In the first embodiment, a first lens group G1includes, in order from the surface of the reticle R, a biconvex lens, a biconcave lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, and parallel plane plates. The second lens group includes, in order from the surface of the reticle R, a biconvex lens, a biconcave lens, a biconvex lens, a biconcave lens, a biconvex lens, a meniscus lens whose concavity faces the side of the surface of the reticle R, a biconvex lens, a

meniscus lens whose convexity faces the side of the surface of the reticle R, and a negative meniscus lens LS whose concavity faces the surface of the reticle R and is formed with an aspherical surface AS1 on the side of the reticle R. The parallel plane plates in the first lens group G1 include a plane mirror M2 which is made by polishing a part of the lens to function as a first optical path deflection member. The image of the reticle R is formed once in the vicinity of the plane mirror M2. Also in the present embodiment, the concave minor M1 is formed on an aspherical surface AS2.

[0019]

In addition, the second imaging optical system S2 includes, in order from the surface of the reticle R, a biconvex lens, a meniscus lens whose concavity faces the side of the surface of the reticle R, a biconvex lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, a biconvex lens, an aperture stop AP, a bioconvex lens, a meniscus lens whose a surface is formed with an aspherical surface AS3 in the side of the reticle R and whose convexity faces the surface of the reticle R, a meniscus lens whose convexity faces the side of the surface of the reticle R, a meniscus lens whose convexity faces the side of the surface of the reticle R, a biconcave lens, a meniscus lens whose concavity faces the side of the surface of the reticle R, and a meniscus lens whose convexity faces the side of the surface of the reticle R. Here, in the present embodiment, a plane mirror M3 is arranged as an optical path deflection member between the first lens and the second lens of the second imaging optical system S2 so that the surface of the reticle R and the surface of a wafer W are arranged in parallel.

Surface No.	r	d	Glassy material		
	0.000	50.000		R	
1	1827.099	25.000	SiO_2	S1	G1
2	-391.019	13.420			
3	-396.812	25.000	SiO_2		
4	829.284	1.000			
5	459.609	25.000	SiO_2		
6	745.296	1.000			
7	488.042	25.000	SiO_2		
8	586.033	25.000			
9	0.000	35.000	SiO_2		
10	0.000	16.000			
11	361.664	32.175	CaF_2		G2
12	-449.989	1.000			
13	-561.169	20.000	SiO_2		
14	255.230	1.000			
15	223.249	39.738	CaF_2		
16	-756.196	57.483			
17	-315.859	20.000	SiO_2		
18	299.543	1.000			
19	260.236	32.584	CaF_2		
20	-675.594	211.188			

21	-163.356	20.000	SiO_2	
22	-252.267	38.241		
23	2280.139	25.000	SiO_2	
24	-1082.014	3.367		
25	556.937	40.000	SiO_2	
26	4236.526	156.695		
27	-215.826	25.000	SiO_2	LS AS1
28	-4417.336	33.561		
29	-354.342	-33.561		M1 AS2
30	-4417.336	-25.000	SiO_2	LS
31	-215.826	-156.695		AS1
32	4236.526	-40.000	SiO_2	
33	556.937	-3.367		
34	-1082.014	-25.000	SiO_2	
35	2280.139	-38.241		
36	-252.267	-20.000	SiO_2	
37	-163.356	-211.188		
38	-675.594	-32.584	CaF_2	
39	260.236	-1.000		
40	299.543	-20.000	SiO_2	
41	-315.859	-57.483		
42	-756.196	-39.738	CaF_2	
43	223.249	-1.000		
44	255.230	-20.000	SiO_2	
45	-561.169	-1.000		
46	-449.989	-32.175	CaF_2	
47	361.664	-5.000		
48	0.000	235.151		M2
49	687.782	30.000	SiO_2	S2
50	-1403.174	170.000		
51	0.000	-150.026		M3
52	262.520	-25.000	SiO_2	
53	474.401	-1.304		
54	-632.711	-27.786	SiO_2	
55	5490.382	-168.081		
56	-1783.259	-25.000	SiO_2	
57	-321.439	-4.402		
58	-357.850	-44.750	CaF_2	
59	3152.678	-173.787		
60	0.000	-28.467		AP
61	-566.009	-45.000	CaF_2	
62	806.950	-1.000		
63	-212.463	-31.096	CaF_2	AS3
64	-368.988	-65.190		
65	-260.201	-44.295	SiO_2	
66	-544.105	-1.000		
67	-169.071	-31.373	CaF_2	
68	-824.497	-9.524		
69	1558.569	-30.000	SiO_2	
70	-466.123	-8.738		

71	7503.078	-29.965	SiO_2	
72	566.609	-15.714		
73	-197.683	-64.000	SiO_2	
74	-163.285	-17.000		
75	0.000			W

Constant of the cone K and aspherical surface constant C

	AS1	AS2	AS3
	r27 (=r31)	r29 (M1)	r63
K	0.000000	0.000000	0.000000
C_4	$0.184947*10^{-8}$	$0.820832*10^{-9}$	$0.184651*10^{-8}$
C_6	$0.211178*10^{-12}$	$0.447187*10^{-13}$	$0.427327*10^{-13}$
C_8	$-0.382898*10^{-17}$	$-0.564120*10^{-18}$	$0.101914*10^{-17}$
C_{10}	$0.152790*10^{-21}$	$0.229674*10^{-22}$	$-0.159307*10^{-22}$
C_{12}	$-0.561578*10^{-26}$	$-0.558227*10^{-27}$	$0.167653*10^{-26}$

As described above, in the present embodiment, an NA is 0.6, the image height Y is available from 5 to 18.6, and thus diameters of all optical members showed about 20 for the catadioptric optical system. Fig. 2 shows a horizontal aberration diagram for the catadioptric optical system of the present embodiment. Aberrations are measured for each wavelength using the image height Y = 18.6 for (a) and the image height Y = 5 for (b). As is clear from Fig. 2, aberrations are corrected very well in the catadioptric optical system of the present embodiment.

Second Embodiment

In the second embodiment, a first lens group G1 includes, in order from the surface of the reticle R, a meniscus lens whose convexity faces the side of the surface of the reticle R, a biconvex lens, a biconcave lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, and parallel plane plates. In addition, the second lens group G2 includes, in order from the surface of the reticle R, a biconvex lens, a meniscus lens whose concavity faces the side of the surface of the reticle R, a biconvex lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, biconcave lens, biconvex lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, a biconvex lens, a meniscus lens whose concavity faces the side of the surface of the reticle R, and a negative meniscus lens L_S whose concavity faces the side of the surface of the reticle R. The parallel plane plates in the first lens group G1 includes a plane mirror M2 which is made by polishing a part of the lens to function as an optical path deflection member. The image of the reticle R is formed once in the vicinity of the plane mirror M2. Also in the present embodiment, the concave mirror M1 is formed on an aspherical surface AS1.

[0020]

In addition, the second imaging optical system S2 includes, in order from the surface of the reticle R, a biconvex lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, a meniscus lens whose convexity faces the side of the surface of the reticle R, a meniscus lens whose concavity faces the side of the

surface of the reticle R, an aperture stop AP, a biconvex lens whose surface in the side of the reticle R is formed on an aspherical surface AS2, a meniscus lens whose convexity faces the side of the surface of the reticle R, a biconcave lens, a meniscus lens whose convexity faces the side of the surface of the reticle R, a meniscus lens whose convexity faces the side of the surface of the reticle R, and a biconvex lens. Here, in the present embodiment, a plane mirror M3 is arranged between the second lens and the third lens in the second imaging optical system S2 so that surface of the reticle R and the surface of a wafer W are arranged in parallel.

Surface No.	r	d	Glassy material		
	0.000	45.000		R	
1	281.775	18.000	SiO_2	S1	G1
2	195.859	1.598			
3	196.715	40.418	SiO_2		
4	-480.361	14.536			
5	-548.718	20.000	SiO_2		
6	204.428	5.448			
7	203.274	20.000	SiO_2		
8	401.273	25.000			
9	0.000	35.000	SiO_2		
10	0.000	15.500			
11	303.555	30.000	CaF_2		G2
12	-1740.057	5.924			
13	-425.354	20.000	SiO_2		
14	-2761.815	1.849			
15	300.937	40.000	CaF_2		
16	-2581.928	1.849			
17	288.864	20.000	SiO_2		
18	177.975	57.224			
19	-175.888	20.000	SiO_2		
20	764.840	0.500			
21	342.881	36.406	CaF_2		
22	-329.279	48.341			
23	270.936	25.000	SiO_2		
24	328.277	66.732			
25	778.307	40.000	SiO_2		
26	-518.576	15.753			
27	-223.579	25.000	SiO_2		
28	-658.513	42.435			
29	-229.025	25.000	SiO_2	LS	
30	-1514.955	17.542			
31	-332.936	-17.542		M1	AS1
32	-1514.955	-25.000	SiO_2	LS	
33	-229.025	-42.435			
34	-658.513	-25.000	SiO_2		
35	-223.579	-15.753			
36	-518.576	-40.000	SiO_2		
37	778.307	-66.732			

38	328.277	-25.000	SiO_2	
39	270.936	-48.341		
40	-329.279	-36.406	CaF_2	
41	342.881	-0.500		
42	764.840	-20.000	SiO_2	
43	-175.888	-57.224		
44	177.975	-20.000	SiO_2	
45	288.864	-1.849		
46	-2581.928	-40.000	CaF_2	
47	300.937	-1.849		
48	-2761.815	-20.000	SiO_2	
49	-425.354	-5.924		
50	-1740.057	-30.000	CaF_2	
51	303.555	-0.500		
52	0.000	233.000		M2
53	415.207	31.117	CaF_2	S2
54	-631.341	0.500		
55	306.049	20.000	SiO_2	
56	218.635	150.000		
57	0.000	-165.240		M3
58	-711.482	-25.000	SiO_2	
59	-2123.013	-302.795		
60	3482.765	-30.000	SiO_2	
61	654.764	-15.000		
62	0.000	-59.904		AP
63	-230.331	-70.000	CaF_2	AS2
64	1603.607	-0.500		
65	-204.918	-28.538	SiO_2	
66	-602.518	-14.615		
67	1240.449	-30.000	SiO_2	
68	-510.567	-0.500		
69	-308.492	-70.000	SiO_2	
70	-714.386	-0.500		
71	-170.397	-45.000	SiO_2	
72	-62.983	-4.156		
73	-63.147	-62.343	SiO_2	
74	766.887	-17.000		
75	0.000			W

Constant of the cone K and aspherical surface constant C

	AS1	AS2
	r31 (M1)	r63
K	0.000000	0.000000
C_4	$0.815186*10^{-9}$	$0.371510*10^{-8}$
C_6	$0.106110*10^{-13}$	$0.507303*10^{-13}$
C_8	$0.216157*10^{-18}$	$0.416256*10^{-18}$
C_{10}	$-0.473987*10^{-23}$	$0.261764*10^{-22}$
C_{12}	$0.490366*10^{-27}$	$-0.397276*10^{-27}$

As described above, in the present embodiment, an NA is 0.6, the image height Y is available from 5 to 18.6, and thus diameters of all optical members

showed about 20 for the catadioptric optical system. Fig. 4 shows a horizontal aberration diagram for the catadioptric optical system of the present embodiment. Aberrations are measured for each wavelength using the image height Y = 18.6 for (a) and the image height Y = 5 for (b). As is clear from Fig. 4, aberrations are corrected very well in the catadioptric optical system of the present embodiment.

[0021]

Effects of the Invention

As described above, the present invention can provide a catadioptric optical system which attains a large numerical aperture in the ultraviolet wavelength region and a practically compact size in the entire optical system, provides resolution of quarter micron levels, and is easy to manufacture.

Brief Description of the Drawings

Fig. 1

Fig. 1 is a structural diagram of a catadioptric optical system according to a first embodiment.

Fig. 2

Fig. 2 is an aberration diagram of the catadioptric optical system according to the first embodiment.

Fig. 3

Fig. 3 is a structural diagram of catadioptric optical system according to a second embodiment.

Fig. 4

Fig. 4 is an aberration diagram of the catadioptric optical system according to the second embodiment.

Description of Symbols

S1	first imaging optical system
S2	second imaging optical system
G1	first lens group
G2	second lens group
M1	concave mirror
M2	first optical path deflection member
M3	second optical path deflection member
AS	surface formed on an aspherical surface
AP	aperture stop
R	reticle
W	wafer